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Development and Flights of Ant-Plane UAVs for Aerial Filming and Geomagnetic Survey in Antarctica

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***Abstract*—** Two types of Unmanned Aerial Vehicles (UAVs) named "Ant-Plane UAVs" are developed for aerial geomagnetic survey and filming in summer Antarctica. In order to accumulate expertise, as well as to demonstrate and to promote UAVs' use potential for scientific mission in Antarctica where activities using manned aircraft are not easy, several flights were made during 2011-2012 Antarctic summer season, by which precious geomagnetic data and onboard video images were successfully acquired. The UAV took off from the glacier near St. Kliment Ohridski Station of Bulgaria in Livingston Island to the area over Deception Island. The island is located 30 km off the Station. Total distance flew in the survey flight was more than 300 km. The geomagnetic data obtained by the UAV has become the world's first geomagnetic data above Deception Island. This paper describes the UAVs developed, the flight results in Antarctica, obtained expertise and lessons learned.

***Keywords*—** UAVs, Geomagnetic Survey, Antarctica.

I. INTRODUCTION

Unmanned Aerial Vehicles (UAVs) are useful and cost-effective tools for scientific research that require measurements and observations over wide spatial range. This is also true for extreme environments especially in Antarctica where research activities using manned aircraft are not easy. The operation of manned aircraft in such area is demanding, large scale, and sometimes life threatening to the pilots and researchers onboard. Aircraft are usually owned or chartered by an expedition team, and mainly used for transportation of goods and the personnel. Their usage is usually based on predetermined flight plans, and is often inconvenient to use in quickly changing situations.

Several groups have already attempted to use UAVs for scientific missions in the polar regions ([1]-[4]) with difficulties mainly due to severe environmental issues. Other than those, experimental UAVs named "Ant-Plane UAVs" were developed. Attempts of their deployment for aerial geomagnetic survey, meteorological observations, and aerial filming in Antarctica were made. [5]-[9]. In Antarctic summer season from December 2011 to January 2012, two Ant-Plane-3s and two Ant-Plane-6s were brought to Livingston Island in South Shetland Islands, which is located north of Antarctic Peninsula as shown in **Figure 1**. Several flight attempts were made there, including the ones with the successful acquisition of geomagnetic data and video images over the northern half part of Deception Island of which location is approximately 30 km south of Livingston Island. Deception Island is an active volcanic island of which shape is like a broken ring. Although the geomagnetic data around the island has been acquired by surveillance ships [10], the data above the island itself has not been obtained yet due to its harsh conditions. The geomagnetic data acquired by Ant-Plane UAVs mission became the world's first data above Deception Island. They are important for the scientists in order to understand the geological structure around the island as well as Bransfield Straight between South Shetland Islands and Antarctic Peninsula. The development of the Ant-Plane UAVs, flights results, obtained expertise, and lessons learned in Antarctica are described in this paper.

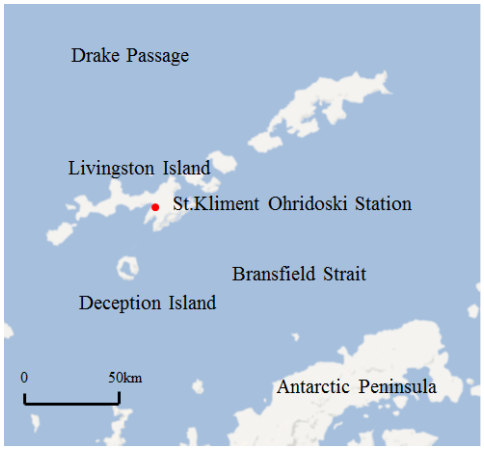

Figure 1 Location of Livingston Island and Deception Island

Ant-Plane UAVs

Two types of Ant-Plane UAVs, Ant-Plane-3 and Ant-Plane-6 have been developed. Ant-Plane-3 is a rather small airplane with conventional configuration. Ant-Plane-6 is a bit larger airplane with a pusher prop and twin-boom configuration. The name "Ant" of "Ant-Plane" comes from the tiny insect "ant" and "Antarctica" because Ant-Planes are very small compared to manned airplanes, and they are intended for use in Antarctica. Although the details of Ant-Planes and the developed automatic flight controller are described in the literature [5]-[6], [8], and [9], synopsis and some special issues are described here for completeness.

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Ant-Plane-3

Ant-Plane-3 shown in **Figure 2** is a low-wing conventional airplane of which span is approximately 2.8 m.

Figure 2 Ant-Plane-3 on the glacier in Livingston Island

It was developed by modifying an off-the-shelf RC model airplane with a 20 cc four-cycle gasoline engine, a large capacity (2000 cc) gasoline tank for longer range, an electric power generator using a brushless motor driven by the engine in order to provide electric power for more than three hours for all onboard system including the automatic flight controller, a 2.4 GHz radio modem for uplink and downlink, and servo actuators. Although Ant-Plane-3 has less payload capacity, it is light, small and easy to handle compared with Ant-Plane-6. The specifications of Ant-Plane-3 are shown in **Table 1**.

A magnetic sensor which utilizes magnetic-resistance element was mounted at the right wing tip, and covered by a fairing (a red right wing tip fairing in **Figure 2**). The servo actuator for right aileron of which position was the closest to the magnetic sensor was wrapped by special anti-magnetic film in order to suppress the influence of the magnetic field generated by the servo actuator on the magnetic sensor. A small HD video camera (GoPro [11]) was mounted at the left wing tip facing its lens to the ground, and covered by a similar fairing in order to reduce aerodynamic drag. The data logger for magnetic measurement was installed in the fuselage connected with a long cable which went through the right wing.

Table 1 Specifications of Ant-Plane-3

Wing span	2.8 [m]
Total weight	9.0 [kg]
Payload weight	1.0 [kg]
Cruising speed	28 [m/s]
Maximum range	300 [km]
Power plant	20 cc four-cycle gasoline engine
Fuel	Gasoline-oil mix
Fuel capacity	2000 [cc]
Electric power generator	30 [W]

Take-offs and landings of the UAVs were done manually using a conventional RC transmitter while cruising was controlled by the automatic flight controller. We assumed take-offs and landings will be done on snow surface of glacier, and skis are prepared as shown in **Figure 3**.

Figure 3 The skis prepared for Ant-Plane-3

Since the optimum installation angle of the skis changes depending on the snow condition, its angle which was determined by the strength of the bungee cord supporting the ski elastically had to be adjusted. The UAV was also equipped with a parachute recovery system stowed in the canopy. It could be used in case of emergency.

Ant-Plane-6

Ant-Plane-6 has the configuration with a pusher prop and twin booms as shown in **Figure 4**.

Figure 4 Ant-Plane-6 on the glacier in Livingston Island

It was developed from scratch aiming at the geomagnetic measurement and filming with larger payload capacity (5 kg). It is equipped with a two-cycle twin-cylinder 86 cc gasoline engine and a large fuel tank of which capacity is 10 litters for flights ranging more than 500 km of distance. The specifications of Ant-Plane-6 are shown in **Table 2**.

A magnetic sensor using a flux gate sensor was mounted at the tip of an aluminium nose boom covered by a fairing (a red fairing at the tip of the nose boom in **Figure 4**). The reason for this installation was the same as in Ant-Plane-3, i.e. to suppress the influence of the magnetic field of the vehicle on the measurement. Ant-Plane-6 was also equipped with an electric power generator, skis, a small HD video camera (GoPro [11]) at the bottom of the nose facing its lens to the front as shown in **Figure 4**, and an emergency parachute recovery system.

Table 2 Specifications of Ant-Plane-6

Wing span	3.0 [m]
Total weight	25.0 [kg]
Payload weight	5.0 [kg]
Cruising speed	33 [m/s]
Maximum range	500 [km]
Power plant	86 cc two-cycle gasoline engine
Fuel	Gasoline-oil mix
Fuel capacity	10,000 [cc]
Electric power generator	30 [W]

The automatic flight control system for all Ant-Plane UAVs uses two Renesas H8S-2638 (20 MHz) microprocessors. A simple PID control law using airspeed and absolute pressure for longitudinal control, yaw-rate, lateral acceleration, and COG (Course over Ground) for lateral and directional control is implemented as well as a guidance law using a GPS current position and waypoints [5].

II. Flight and Results

Our team including the authors and two technicians stayed at St. Kliment Ohridski Station of Bulgaria in Livingston Island for about two weeks in December 2011, and attempted to fly the UAVs. After the assembly of Ant-Plane UAVs, we adjusted the angles of skis by taxi test on snow surface. The angle of the ski changes in taxi on snow surface and in the air because the force acting on the ski changed whether the UAV was on snow or in the air. The angle also changed depending on the snow condition, i.e. snow temperature. The angles had to be adjusted on trial and error basis and it took considerable time to determine optimal angles.

South Shetland Islands are located at the edge of the storm zone around latitude 60 s degrees south (so called "Screaming Sixties"). Weather conditions were often severe even in summer season in Antarctica. However, air temperature on the ground was not so severe in summer, and it was around 0 degrees Celsius in daytime and only -5 to -10 degrees Celsius even at night. Air temperature at pre-planned maximum flight altitude (800 m above Mean Sea Level, MSL) was predicted as utmost around -10 degrees Celsius. All onboard avionics were designed and tested to be used under environment down to -20 degrees Celsius. Major limiting conditions with regard to weather were high wind speed and low cloud base. It became difficult for us to even stay outside when the wind speed was high during UAV operation. When the cloud base was low, and the UAV had to fly in clouds, there was a possibility of structural icing. We had to give up flying in such conditions since the UAVs were not equipped with de-icers. The typical weather pattern around South Shetland Islands was that a low pressure system passes by every 5 to 7 days. The wind speed often became higher around 10 to 20 m/s when the sky was clear. When the wind speed became low, the cloud base often became low and even low to the ground surface, i.e. fog. The opportunities suitable for the UAV flight were only couple of days during the two weeks. We had to make a decision for the UAV flight based on visual weather observations since detailed weather forecast was not available at the station.

Figure 5 Setup of the ground station

Flights and Results of Ant-Plane-3

Once we made a decision to fly, the UAVs and relevant materials were carried by a sledge towed by a snowmobile (ski-do) to a relatively flat place on glacier together with the team members and some members of the station. The place for take-offs and landings had to be determined considering the wind direction and the snow condition. The ground station was set up on snow as shown in **Figure 5**. Electricity necessary for the ground station was provided by a car battery and a DC-AC inverter.

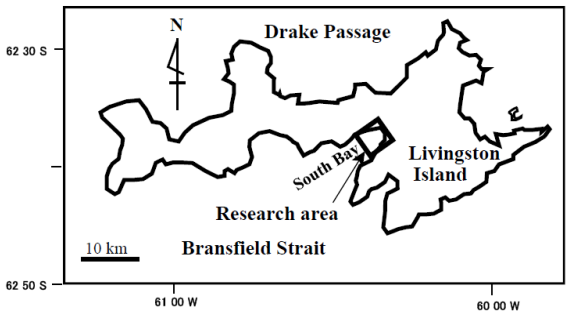

Figure 6 Flight area of Ant-Plant-3

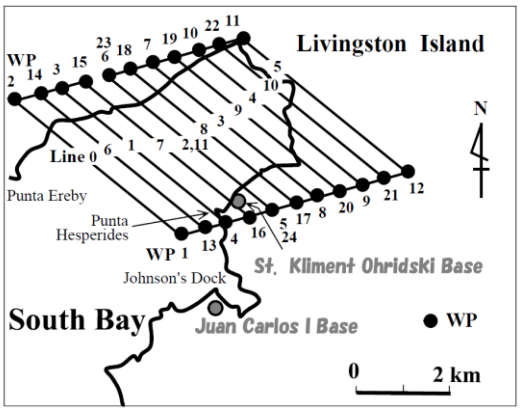

Figure 7 Flight plan and waypoints for Ant-Plane-3

One of the flights of Ant-Plane-3 was that of a grid survey flight at the altitude about 350 m over South Bay at which St. Kliment Ohridski Station of Bulgaria faces as shown in Figure 6 and **Figure 7**.

Geomagnetic measurement and filming were attempted using 24 waypoints, but unfortunately, geomagnetic data were not recorded correctly due to the failure of the data logger. However, video images were recorded very clearly as shown in **Figure 8**. The edge of a glacier is captured very clearly. Several crevasses and hidden crevasses were also recorded clearly, and it implied that the video image taken by UAVs may be used for route planning for ground expedition.

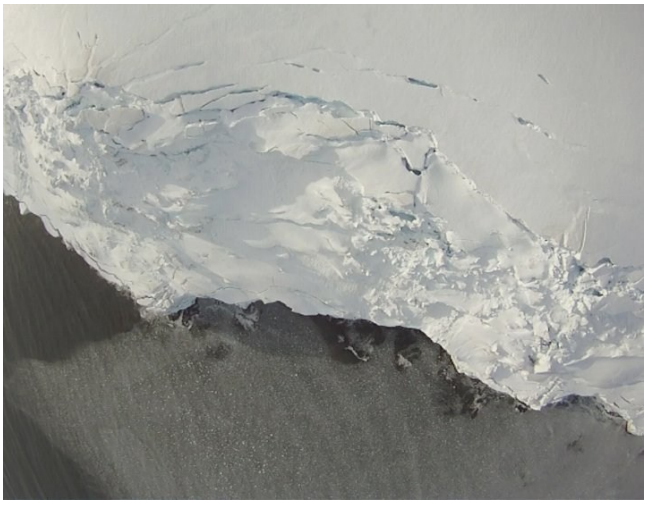

Figure 8 One frame of the video image captured by Ant-Plane-3

Time history of GPS altitude was shown in **Figure 9**, and flight track recorded by GPS logger in **Figure 10**.

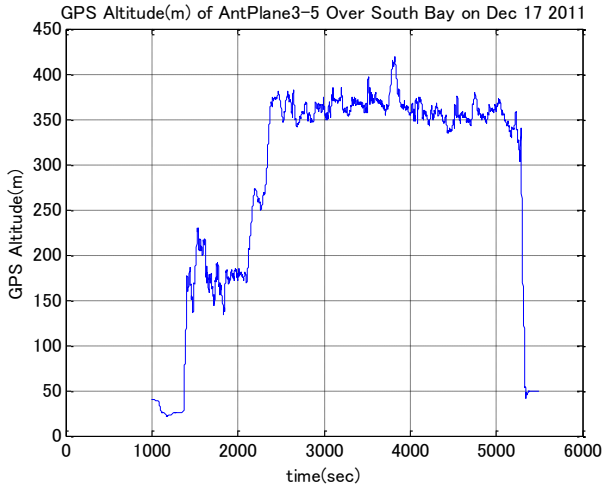

Figure 9 Time history of altitude of Ant-Plane-3 over South Bay

Overall flight time was one hour and seven minutes, and the total flight distance was 105.4 km. Commanded pressure altitude was 350 mMSL, and slight fluctuations in altitude and also in flight track were observed as shown in **Figure 9** and **Figure 10** respectively at several places. These were probably due to the effect of wind, but the performance is almost satisfactory.

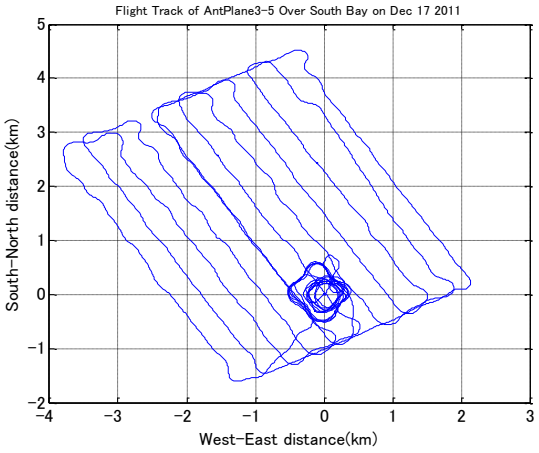

Figure 10 2D flight track of Ant-Plane-3 flight over South Bay

Flights and Results of Ant-Plane-6

One of the flights of Ant-Plane-6 was also the grid survey flight over the northern half part of Deception Island of which location is approximately 30 km south of Livingston Island as shown in **Figure 11** and **Figure 12**.

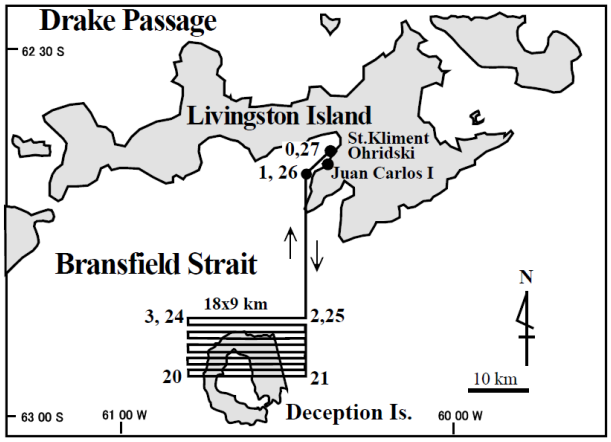

Figure 11 Flight plan of Ant-Plane-6 from Livingston Island to Deception Island

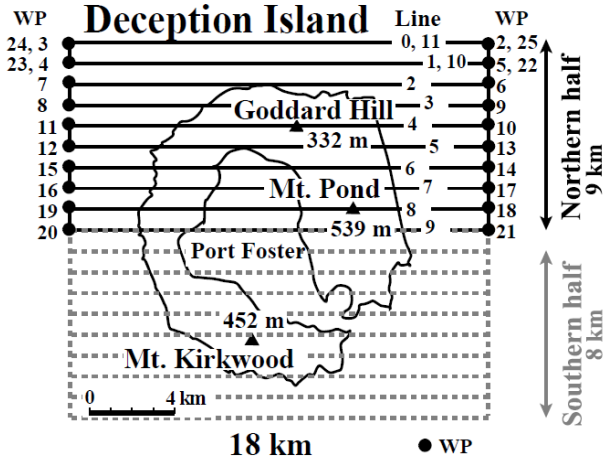

Figure 12 Flight plan and waypoints for Ant-Plane-6 over Deception Island

Ant-Plane-6 took off at about 2:20 am because the opportunity was thought to be the final due to the time limit for the stay at the station. Most of its flight was out of visual range, and the UAV returned to Livingston Island and landed at around 5:27 am. Total flight time was three hours and seven minutes, and total distance was 302.4 km. Geomagnetic measurement and filming were also attempted, and both were done successfully. One image over Deception Island taken by the camera is shown in **Figure 13**. It clearly shows the shape and geography of Deception Island. The geomagnetic sensor head and its supporting boom are seen upper centre of the picture.

Figure 13 Video image of Deception Island captured by Ant-Plane-6

Time history of GPS altitude is shown in Figure 14 and 3D flight track in **Figure 15**. Commanded pressure altitude was 800 mMSL, and slight decrease in altitude was observed probably due to the change in static pressure accompanied by weather deterioration. However, the performance was also almost satisfactory.

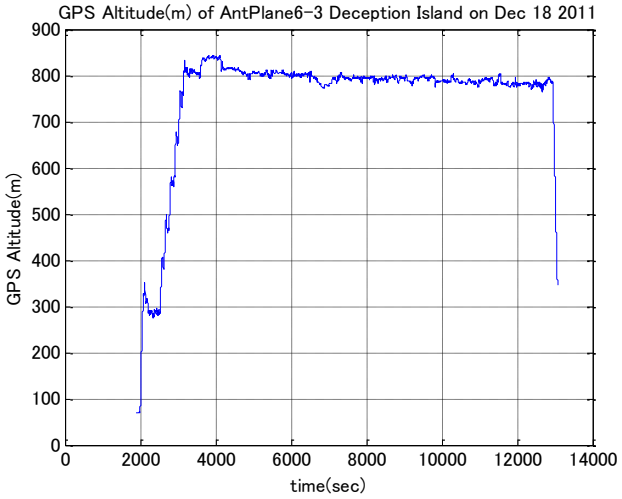

Figure 14 Time history of altitude in the flight of Ant-Plane-6 from Livingston Island to Deception Island

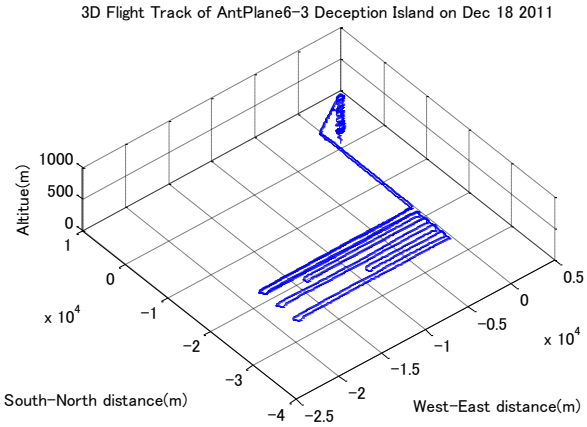

Figure 15 3D flight track of Ant-Plane-6 from Livingston Island to Deception Island

The magnetic anomaly map obtained by this flight is shown in **Figure 16**. Although detailed analysis is in progress, it has been confirmed that the result shown in **Figure 16** is consistent with the magnetic anomaly map around the island obtained by using ships [10]. This data has become the world's first geomagnetic data above Deception Island. The result shows that the UAVs are quite useful for scientific missions especially in hazardous environment like Antarctica.

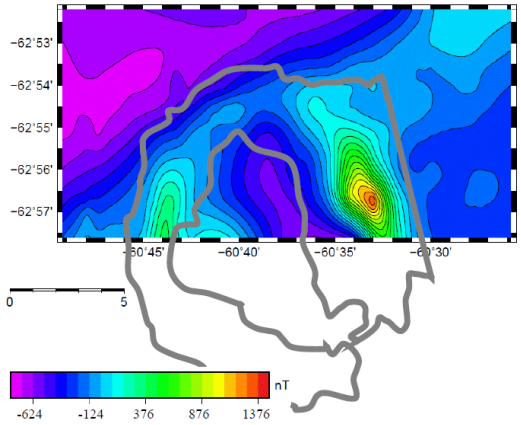

Figure 16 Magnetic anomaly map obtained by Ant-Plane-6

III. CONCLUSION

Ant-Plane-3 and Ant-Plane-6 have been developed for scientific missions in Antarctica. They are intended to be used for aerial geomagnetic survey and filming. Ant-Plane-3 was a conventional airplane modified from off-the-shelf RC model airplane. Other than being light, small, and easy to handle, it can fly more than 300 km of distance despite having small payload capacity. Ant-Plane-6 was designed from scratch with a pusher prop, twin-boom configuration, larger payload capacity, and longer range more than 500 km.

Flight results show that video images are quite clear and useful for several observation purposes. The magnetic anomaly data taken by the flight of Ant-Plane-6 has become the world's first data above Deception Island, and show the consistency with the magnetic anomaly data around the island

independently obtained by ships. The usefulness of UAVs for scientific missions and the acquisition capability of practical data such as video images and magnetic measurement in harsh environment like Antarctica have been proved.

Based on this success and expertise, aerosol density observation and sampling up to 10 km of altitude using the combination of a balloon and a UAV has performed and also made success in January 2013 at Syowa Station of Japan in Antarctica. We are planning to make the observation altitude higher up to 30 km in the near future and making effort to make the UAV more reliable and easier to use even for the scientists as the future work.

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